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**ELECTROLUMINESCENT MATERIALS**

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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(21) International Application Number: <b>PCT/GB00/00268</b> (22) International Filing Date: <b>31 January 2000 (31.01.00)</b> (30) Priority Data: <b>9901971.3</b> <b>1 February 1999 (01.02.99)</b> <b>GB</b> (71) Applicant ( <i>for all designated States except US</i> ): <b>SOUTH BANK UNIVERSITY ENTERPRISES LTD [GB/GB]; 103 Borough Road, London SE1 0AA (GB).</b> (72) Inventor; and (75) Inventor/Applicant ( <i>for US only</i> ): <b>KATHIRGAMANATHAN, Poopathy [GB/GB]; 14 Sandhurst Avenue, North Harrow, Middlesex HA2 7AP (GB).</b> (74) Agent: <b>COHEN, Alan, Nicol; 2 Grove Place, Tatsfield, Westerham, Kent TN16 2BB (GB).</b>			(81) Designated States: <b>AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</b>  <b>Published</b> <i>Without international search report and to be republished upon receipt of that report.</i>
(54) Title: <b>ELECTROLUMINESCENT MATERIALS</b>			
(57) Abstract  An electroluminescent material which can form electroluminescent devices which emit light in the ultra-violet region of the spectrum which comprises an organic metallic complex of a transition metal, lanthanide or actinide and a polyamine ligand particularly gadolinium ethylenediaminetetraacetate sodium salt, Na[Gd(EDTA)] and gadolinium europium ethylenediaminetetraacetate salts, Gd[Eu(EDTA)] <sub>3</sub> .			

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## Electroluminescent Materials

The present invention relates to electroluminescent materials which can emit light in the ultra-violet region of the spectrum and devices made using such materials.

- 5     Materials which emit light when an electric current is passed through them are well known and used in a wide range of display applications and organic polymers have been proposed as useful in electroluminescent devices, but using these polymers it is not possible to obtain pure colours, they are expensive to make and have a relatively low efficiency.
- 10     Another compound which has been proposed is aluminium quinolate, but this requires dopants to be used to obtain a range of colours and has a relatively low efficiency.
- 15     In an article in Chemistry letters pp 657-660, 1990 Kido et al disclosed that a terbium (III) acetyl acetonate complex was green electroluminescent and in an article in Applied Physics letters 65 (17) 24 October 1994 Kido et al disclosed that a europium (III) triphenylene diamine complexes was red electroluminescent but these were unstable in atmospheric conditions and difficult to produce as films.
- 20     The complexes disclosed in these articles had a relatively low photoluminescent efficiency and were only able to produce green or red light and other colours could not be produced.
- 25     Patent Applications WO 98/58037 and WO 98/55561 disclose electroluminescent materials which emit light in the visible spectrum and disclose electroluminescent devices incorporating these materials.
- 30     The wavelength of the emitted light from an organo metallic complex which is an electroluminescent material depends on the metal or metals and the ligands.

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In general the shorter the wavelength of the emitted light the harder it is to obtain effective electroluminescent materials and in particular electroluminescent materials which emit light in the ultra-violet region of the spectrum have hitherto not been possible to produce.

5

An electroluminescent material which can emit ultra-violet light would have a range of applications and would enable there to be a source of ultra-violet light without the need for high temperature or complex high energy or vacuum equipment and so could replace such sources of ultra-violet light.

10

For example, there are devices and displays etc. where ultra-violet light is used to excite other materials to cause these other materials to fluoresce in the visible spectrum.

15

We have now devised organo-metallic complexes which can emit ultra-violet light.

According to the invention there is provided an electroluminescent material which emits light in the ultra-violet region of the spectrum which comprises an organic metallic complex of a transition metal, lanthanide or actinide and a polyamine ligand.

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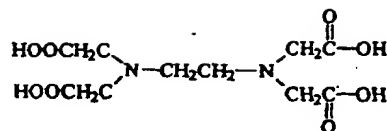
The preferred metal is gadolinium in the III state.

Preferred ligands are ethylene diamine tetramine EDTA, DCTA, DTPA and TTHA.

25

The structural formulae of these compounds in the acetic acid form are shown below.

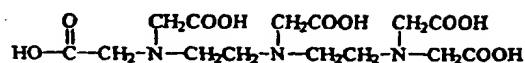
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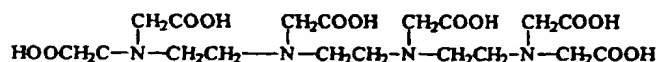
EDTA



DCTA

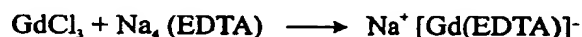


DTPA



TTHA

The organo metallic complexes can be made by the reaction of gadolinium chloride  
 5 with an alkali metal salt of the amine e.g. the sodium salt, for EDTA the reaction is



For the other polyamine the corresponding alkali metal salt is used.

10 With polyamines which are more than tri-functional e.g. EDTA, DCTA, DTPA, TTHA the complexes can be in the form of a salt e.g. an alkali metal salt and can be used in this form. Alternatively a transition metal, lanthanide or actinide salt e.g.  $\text{Ln}^+[\text{Ln}(\text{EDTA})]_3$  where Ln and  $\text{Ln}^+$  is a transition metal, lanthanide or actinide and preferably a lanthanide e.g. Gd, Sm, Eu, Tb, Dy, etc.

15

Particularly preferred mixed complexes are the gadolinium complexes e.g.  $\text{Gd}[\text{Eu}(\text{EDTA})]_3$ .

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It has surprisingly been found that the lanthanide salts of the organo-metallic complexes exhibit a different electroluminescent spectrum than mixed organo-metallic complexes.

- 5     The mixed lanthanide salts can be made by reacting a lanthanide chloride with a lanthanide polyamine complex.

10    The materials of the present invention can be incorporated into electroluminescent devices which emit ultra-violet light and the invention include such electroluminescent devices.

15    The ultra-violet light emitting devices of the invention comprise a transparent substrate which is a conductive glass or plastic material which acts as the anode, preferred substrates are conductive glasses such as indium tin oxide coated glass, but  
20    any glass which is conductive or has a conductive layer can be used. Conductive polymers and conductive polymer coated glass or plastics materials can also be used as the substrate. The electroluminescent material can be deposited on the substrate directly by evaporation from a solution of the material in an organic solvent. The solvent which is used will depend the material for example alcohols such as ethanol, ketones such as acetone and methyl acetylacetonate and chlorinated hydrocarbons such as dichloromethane are suitable in many cases.

25    Alternatively the material can be deposited by spin coating or by vacuum deposition from the solid state e.g. by sputtering or any other conventional method can be used.

In one embodiment there is a hole transporting layer deposited on the transparent substrate and the electroluminescent material is deposited on the hole transporting layer. The hole transporting layer serves to transport; holes and to block the electrons, thus preventing electrons from moving into the electrode without

- 5 -

recombining with holes. The recombination of carriers therefore mainly takes place in the emitter layer.

5 Hole transporting layers are used in polymer electroluminescent devices and any of the known hole transporting materials in film form can be used.

The hole transporting layer can be made of a film of an aromatic amine complex such as poly(vinylcarbazole), N,N'-diphenyl-N,N'-bis (3-methylphenyl)-1,1'-biphenyl -4,4'-diamine (TPD), polyaniline etc.

10

Optionally dyes such as fluorescent laser dyes, luminescent laser dyes can be included so that these dyes fluoresce in the ultra-violet light to give emitted light of a particular colour spectrum.

15 Preferably the electroluminescent material is mixed with a polymeric material such as a polyolefin e.g. polyethylene, polypropylene etc. and preferably polystyrene. Preferred amounts of active material in the mixture is from 95% to 5% by weight of active material and more preferably 25 to 20% by weight.

20 The hole transporting material can optionally be mixed with the electroluminescent material in a ratio of 5-95% of the electroluminescent material to 95 to 5% of the hole transporting compound. In another embodiment of the invention there is a layer of an electron injecting material between the cathode and the electroluminescent material layer, this electron injecting material is preferably a metal complex such as a metal  
25 quinolate e.g. an aluminium quinolate which will transport electrons when an electric current is passed through it. Alternatively the electron injecting material can be mixed with the electroluminescent material and co-deposited with it.

30 In a preferred structure there is a substrate formed of a transparent conductive material which is the anode on which is successively deposited a hole transportation



layer, the electroluminescent material layer and an electron injection layer which is connected to the anode. The anode can be any low work function metal e.g. aluminium, calcium, lithium, silver/magnesium alloys etc.,

- 5     There can be a layer or layers containing a fluorescent material in the device so that the ultra-violet light emitted will cause the material to fluoresce and emit light of a particular colour spectrum.

The invention is described in the following examples.

10

Example 1

Gadolinium ethylenediaminetetraacetate sodium salt, Na[Gd(EDTA)]

Gadolinium chloride (10 mmol) was dissolved in water (5 ml). Ethylenediaminetetraacetic acid, tetrasodium salt hydrate (10 mmol) was dissolved  
15     in water (10 ml) and added portionwise to the gadolinium chloride solution. The solution became warm, and after ca. 15 minutes, a white precipitate was formed. The mixture was left for a further 2 hours. The precipitate was filtered off to give a white solid which was washed with water (2 x 5 ml) and dried in air to yield Gadolinium ethylenediaminetetraacetate sodium salt, Na[Gd(EDTA)]

20

Example 2

Gadolinium europium ethylenediaminetetraacetate salts, Gd[Eu(EDTA)]<sub>3</sub>

Europium ethylenediaminetetraacetate sodium salt Na[Eu(EDTA)] (4.5 mmol) was dissolved in methanol (30 ml). Gadolinium chloride (1.5 mmol) was dissolved in  
25     water (5 ml) and added portionwise to the europium ethylenediaminetetraacetate sodium salt solution. A white precipitate was immediately formed. The mixture was left for a further 1 hour. The precipitate was filtered off to give a white solid which was washed with methanol (2 x 10 ml) and dried in air to yield the product Gadolinium europium ethylenediaminetetraacetate salts, Gd[Eu(EDTA)]<sub>3</sub>.

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Photoluminescence was excited using 325nm line of Liconix 4207 NB, He/Cd laser. The laser power incident at the sample ( $0.3\text{mWcm}^{-2}$ ) was measured by a Liconix 55PM laser power meter. The radiance calibration was carried out using Bentham radiance standard (Bentham SRS8, Lamp current 4,000A, calibrated by National Physical laboratories, England. The PL studies were carried out on samples or films. The Complexes of the examples were tested and the results shown in the Spectra attached as Figs. 1 and 2.

An electroluminescent device constructed with a film of the compounds of examples 1 and 2 with an indium coated glass as anode and an aluminium cathode emitted light in the ultra-violet spectrum when a low voltage was applied across the film. The light was emitted in the same spectrum ranges as in figs. 1 and 2

## Claims

1. An electroluminescent material which emits light in the ultra-violet region of the spectrum which comprises an organic metallic complex of a transition metal,  
5 lanthanide or actinide and a polyamine ligand.
2. An electroluminescent material as claimed in claim 1 in which the metal is gadolinium in the III state.
- 10 3. An electroluminescent material as claimed in claim 1 or 2 in which the ligand is ethylene diamine tetramine, DCTA, DTPA or TTHA.
4. An electroluminescent material as claimed in claim 3 in which the complex is in the form of a salt .
- 15 5. An electroluminescent material as claimed in claim 4 in which the complex is in the form of an alkali metal salt
6. An electroluminescent material as claimed in claim 4 in which the salt is a  
20 transition metal, lanthanide or actinide salt
7. An electroluminescent material as claimed in claim 4 in which the salt is  $\text{Ln}^*[\text{Ln}(\text{EDTA})]_3$  where Ln and  $\text{Ln}^*$  is selected from transition metals, lanthanides and actinides.
- 25 8. An electroluminescent material as claimed in claim 7 in which Ln and  $\text{Ln}^*$  is selected from Gd, Sm, Eu, Tb, Dy.
9. An electroluminescent material as claimed in any one of claims 1, 4 or 5 in which  
30 the metal complex is  $\text{Gd}[\text{Eu}(\text{EDTA})]_3$ .

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10. An electroluminescent device which comprises a transparent substrate on which is deposited an electroluminescent material as claimed in any one of the preceding claims.
- 5 11. An electroluminescent device as claimed in claims 1 to 10 in which the transparent substrate is a conductive glass or plastic material which acts as the anode.
12. An electroluminescent device as claimed in any one of claims 10 to 11 in which there is a hole transporting layer deposited on the transparent substrate and the  
10 electroluminescent material is deposited on the hole transporting layer.
13. An electroluminescent device as claimed in any one of claims 10 to 12 in which there is a hole transporting material mixed with the electroluminescent material in a ratio of 5 to 95% of the electroluminescent material to 95 to 5% of the hole  
15 transporting compound.
14. An electroluminescent device as claimed in claim 12 or 13 in which the hole transporting layer is an aromatic amine complex.
- 20 15. An electroluminescent device as claimed in claim 14 in which the hole transporting layer is poly(vinylcarbazole), N,N'-diphenyl-N,N'-bis (3-methylphenyl) -1,1' -biphenyl -4,4'-diamine (TPD) or polyaniline.
16. An electroluminescent device as claimed in any one of claims 11 to 15 in which  
25 there is a metal anode in contact with the electroluminescent material.
17. An electroluminescent device as claimed in any one of claims 10 to 16 in which there is a layer of an electron injecting material between the cathode and the electroluminescent material layer

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18. An electroluminescent device as claimed in any one of claims 10 to 17 in which an electron injecting material is mixed with the electroluminescent material and co-deposited with it.
- 5 19. An electroluminescent device as claimed in claim 17 or 18 in which the electron injecting material is a metal complex or oxadiazole or an oxadiazole derivative.
20. An electroluminescent device as claimed in claim 19 in which the electron injecting material is an aluminium quinolate or 2-(4-biphenyl)-5-(4-tert-butylphenyl)-  
10 1,3,4 oxadiazole.
21. An electroluminescent device as claimed in any one of the preceding claims 10 to 20 in which the anode is a metal.
- 15 22. An electroluminescent device as claimed in claim 21 in which the anode is a aluminium, magnesium, lithium, calcium or a magnesium silver alloy.
23. An electroluminescent device as claimed in any one of the preceding claims 10 to 22 in which there are a plurality of layers of electroluminescent material.
- 20 24. An electroluminescent device as claimed in any one of the preceding claims 10 to 23 in which there is a layer or layers which incorporates a dye which fluoresces in ultra-violet light to give emitted light in the colour spectrum.
- 25

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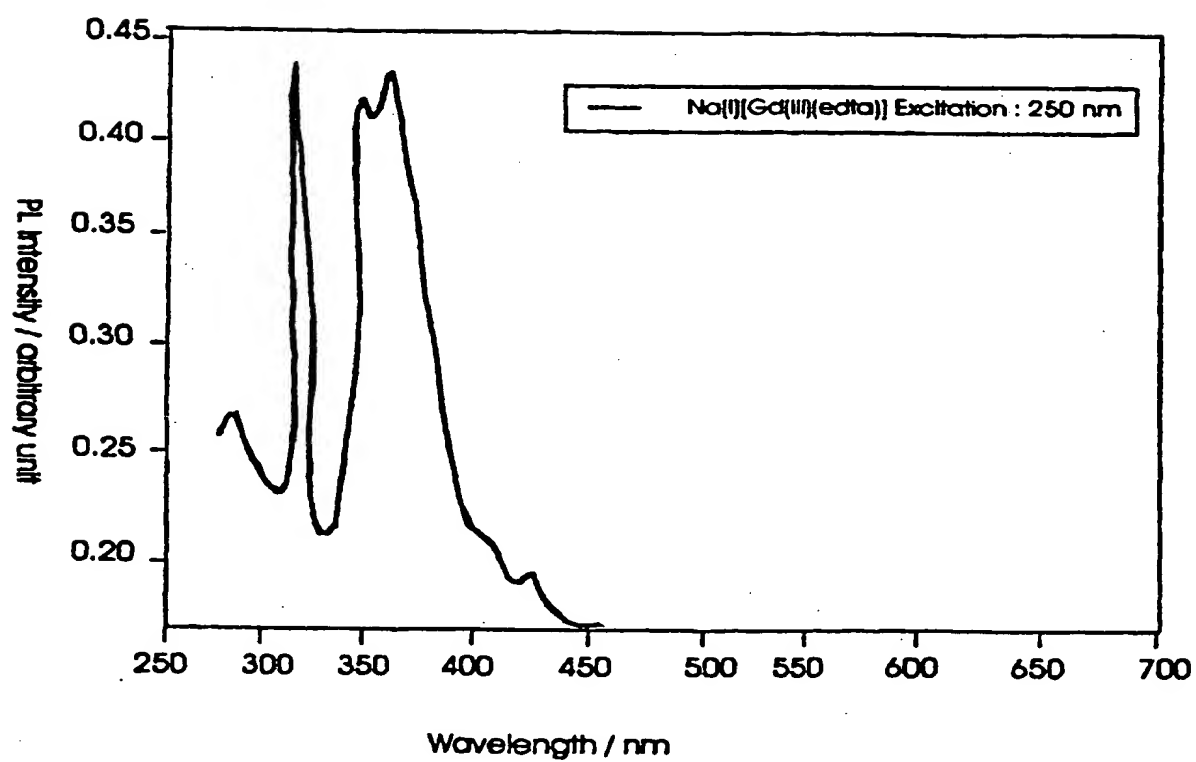


Fig. 1

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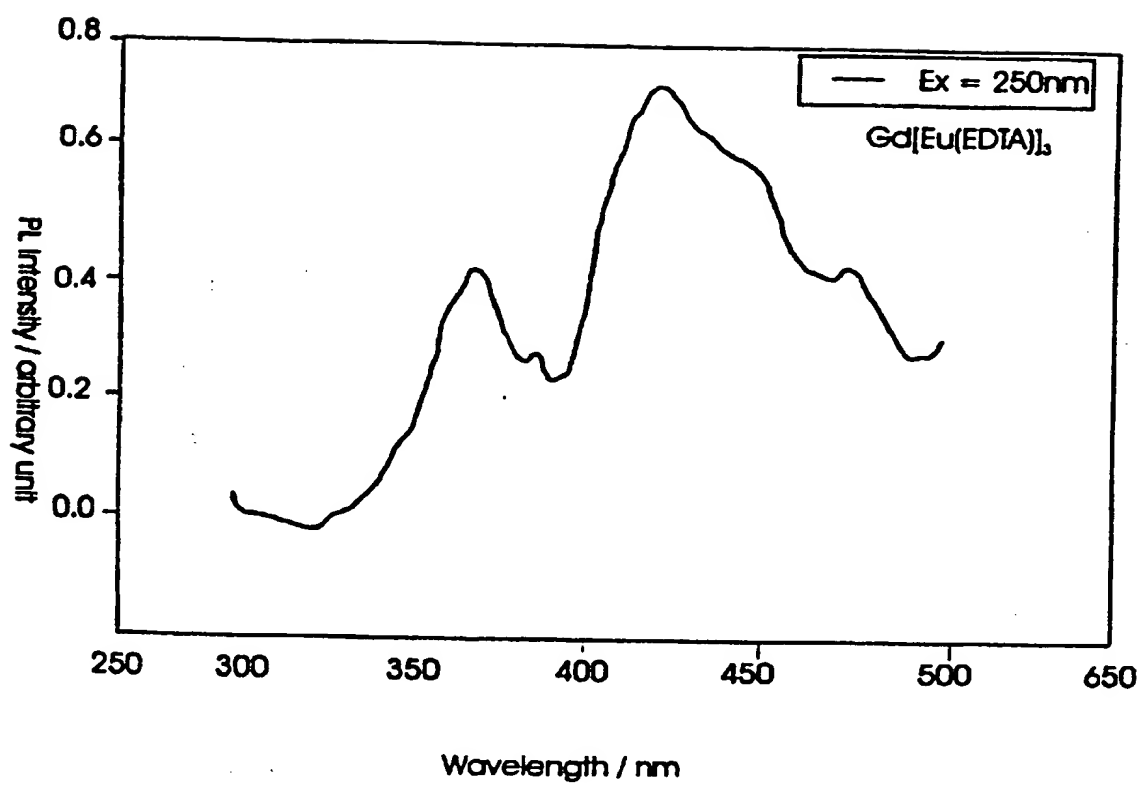


Fig. 2